Pub Health Serv. in Atlanta
already ack— 1581

LARVICIDING

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
MALARIA CONTROL IN WAR AREAS
ATLANTA, GEORGIA OCTOBER 1945

Office

NOT FOR PUBLICATION

CONTENTS

LARVICIDING

Mosquito larviciding is the practice of applying poisons to kill mosquito larvae (wiggletails) in their breeding places. The purpose of this manual is to furnish basic information on where, when, and how to use the different larvicides which may be available for malaria control purposes.

The manual is designed to serve the entire field of subprofessional and professional operations personnel. The material included is designed to acquaint the reader with the several types of larvicides, which type to use for best results, the method of application best suited to different breeding places, and the sizes and capacities of equipment available.

Larvicides commonly used in mosquito control are not effective for more than a few hours. Therefore, they must be applied at intervals of from 7 to 10 days to prevent any mosquito completing its development from egg to adult. Hence, larviciding produces only temporary results and is expensive when applied year after year to the same breeding place.

Larvicides may be classed in general as contact or as stomach poisons, depending on the way they kill larvae, although some larvicides may act both as a contact and as a stomach poison. Diesel oil is a good example of a contact larvicide; paris green is typical of stomach poisons.

The following outline classifies most of the common larvicides according to physical characteristics and method of kill:

A. Dusts - Stomach poisons applied to water surface to kill anopheline larvae.

1. Paris green (copper aceto-arsenite)
2. Calcium and sodium arsenite
3. Pyrethrum powder
4. Phenothiazine
5. DDT (contact and stomach poison)
6. Paraformaldehyde

B. Petroleum Oils - Contact larvicides sprayed on the water surface to kill culicine and anopheline larvae.

1. Diesel or fuel oil (No. 2)
2. Kerosene
3. Waste motor oil (generally diluted with kerosene or diesel oil)

C. Emulsions (mixtures or suspensions of one liquid in another) - Contact larvicides applied by spray to breeding places.

1. Pyrethrum-oil emulsion
2. Petroleum oil-water emulsions
3. DDT emulsion
4. Phenol and cresol emulsions

Larviciding for malaria or mosquito control should be used under the following conditions:

1. To effect *Anopheles* reduction in the quickest possible time during outbreaks of malaria.

2. To furnish temporary protection where larviciding is less expensive and equally or more effective (temporarily) than other methods. (Example, drainage around temporary Army Camps or war housing.)

3. When more permanent methods (such as drainage) are undesirable or impracticable. (Example, a water supply reservoir, a wildlife refuge, a recreational lake, or a river.)

4. To supplement other control measures during floods or similar emergencies. (Example, floods creating breeding places in a normally well-drained area, or breeding of mosquitoes in flooded lowlands as a result of flood damage to levee, etc.)

5. Where more permanent control methods are under way but larviciding is needed for immediate temporary protection. (Example, a large drainage project around a permanent Army post which may take months or years to complete.

Larviciding is the basic method of anopheline mosquito control on the MCWA extra-military zone program, since it is more generally suitable for use on emergency "duration of war" projects. Choice of a larvicide is based on the following considerations:

1. Comparative effectiveness and economy against anopheline mosquitoes under local breeding conditions.

2. Availability of larvicidal materials and equipment including transportation.

3. Local experience and practices.

Principal requirements of a larvicide are:

1. High toxicity to larvae under field conditions.

2. Low cost.

3. Harmlessness to man, animals, and wildlife.

4. Ease of distribution.

In an area containing many breeding places, the preferred method of control should be selected for each principal breeding place or collection of breeding places. The discussions following under Types of Larvicides; Materials, Equipment and Larvicidal Techniques; and Planning and Organization will aid in the selection of method and larvicide.

TYPES OF LARVICIDES

I. DUSTS

Paris green is the most extensively used larvicide for *Anopheles* mosquito control. It is a stomach poison; hence, mosquito larvae must eat the particles in order to be killed. Applied to the water surface, the particles usually float for several hours, and anopheline larvae, which habitually feed at the surface, eat them and are poisoned. While paris green is the most economical larvicide commonly used against anopheline mosquitoes, it is not effective (except under special circumstances) against other mosquito larvae (culicines) which feed below the water surface.

Paris green is usually diluted with a material such as hydrated lime, soapstone, talc, or road dust and applied as a dust mixture with hand or power equipment. Rarely, it is used as a spray in the form of an emulsion or suspension. As a dust mixture in malaria mosquito control, it has the advantage over other larvicides in economy; effectiveness in places overgrown with grasses, pond weeds and other vegetation; harmlessness to fish, waterfowl, plants, men, and animals in the dosages used.

Its principal disadvantages as employed in malaria control are that it kills only larvae of *Anopheles* mosquitoes, fails to kill any pupae (tumblers) or most of the very young (first stage) larvae, and requires favorable atmospheric conditions for effective applica-

tion in many breeding places. Hard rains immediately after dusting may cause the particles to sink before larvae have fed.

A number of other larvicidal dusts have been tried as anopheline or general mosquito larvicides. These have had limited use because they do not meet fully the practical requirements of a good larvicide. Some chemicals which have been tested are calcium and sodium arsenites, copper carbonate, pyrethrum powder, iodoform, and paraformaldehyde.

II. *PETROLEUM OILS (DIESEL, KEROSENE AND CRANKCASE)

Diesel or fuel oil (No. 2) has had wide use both as an anopheline and as a general mosquito larvicide. On malaria control programs, which are concerned only with *Anopheles* mosquitoes, oil larvicides are several times more costly than paris green. However, diesel oil or fuel oil is effective in killing almost all kinds (species) of mosquito larvae, as well as very young larvae and pupae. Fuel oil is used straight, in power or hand operated sprayers; as an oil-water "mixture" in high pressure sprayers; or as an emulsion.

Because of its high cost, kerosene is seldom used to control *Anopheles* larvae. Alone or mixed with waste motor oil, it has been used to larvicide small ponds or pools. Its effectiveness in killing larvae is generally similar to that of diesel oil, although its

**See appendix for description and specifications.*

spreading qualities are different. In other countries, under special conditions of anopheline breeding, kerosene has been used mixed with paris green and water.

Contrary to popular belief, waste motor (crankcase) oil alone is a very poor mosquito larvicide. It has low toxicity, does not spread well, and leaves a dirty unsightly film on the water surface and on vegetation. It has limited usefulness on malaria control operations. Generally, it should be diluted with 2 or 3 parts of kerosene or diesel oil.

Unlike paris green, petroleum oil kills mosquito larvae and pupae by contact. An exposure of one to ten minutes is sufficient to kill, if the oil is satisfactory, but a much longer period may elapse before death occurs.

III. *EMULSIONS

Pyrethrum emulsion is used to some extent in special situations, although it has not had wide application in malaria control. Its harmlessness to fish, plants, animals, and man and its inoffensive appearance and odor make this larvicide especially suitable for control of mosquitoes in ornamental fish ponds fish hatcheries, and the like. It is effective against all species and stages of larvae. The stock emulsion, which contains pvrethrum extract, kerosene, water, and an emulsifier

**See appendix for description and specifications.*

(soap, sodium lauryl sulfate, etc.) is diluted 1 to 10 with water before application. This larvicide had limited use during wartime because of the restricted pyrethrum supply.

Emulsions (mixtures or suspensions of one liquid in another) of diesel oil and kerosene have been developed to reduce the amount of oil necessary for effective larviciding. This is done by adding a chemical (emulsifier) to diesel oil or kerosene to prevent the dispersed oil droplets from separating out. Before spraying on the breeding place, the oil mixture is diluted with water taken from the pond or pool and agitated to form a uniform suspension (emulsion). This results in a dual saving of oil and transportation. Used in this form, as little as six gallons of oil will cover one acre.

Phenol (carbolic acid) and cresol (cresylic acid) larvicides are emulsions that have been used but little in malaria control and are not recommended. They are very poisonous to fish, water plants, waterfowl, animals, and men and should never be used except in special cases and under expert supervision. They have been used in nuisance mosquito control work to larvicide sewage contaminated pools and ponds, sewers, catch basins, and against tree-hole breeding mosquitoes. They are used also as emulsions or are added to petroleum oil to increase its toxicity.

IV. DDT

Recent studies of DDT show it to have good larvicidal properties. Used in extremely small amounts, it is effective and economical. Further testing may prove that it has dependable "residual" (lasting) killing powers at low application rates. However, it has not yet had wide scale use as an anopheline larvicide in this country. At present, DDT is used for recurrent application in spray (solution or emulsion) or dust form. The manner in which DDT kills larvae is not fully known but is probably by contact. Further field tests are necessary before general recommendations can be made.

V. MISCELLANEOUS LARVICIDES

Borax has been used successfully to control mosquito breeding in cisterns, fire barrels, and other similar artificial containers; but it will destroy plants and fish and is not suitable for malaria control operations.

Phenothiazine, a chemical used to treat worms in livestock, is a useful larvicide against pest mosquitoes that breed in flower vases, old tire casings, drinking troughs, and other containers. Because it is very poisonous to fish, it cannot be used generally in malaria or general mosquito control. It is nontoxic to man, animals, and plants in the dosages used.

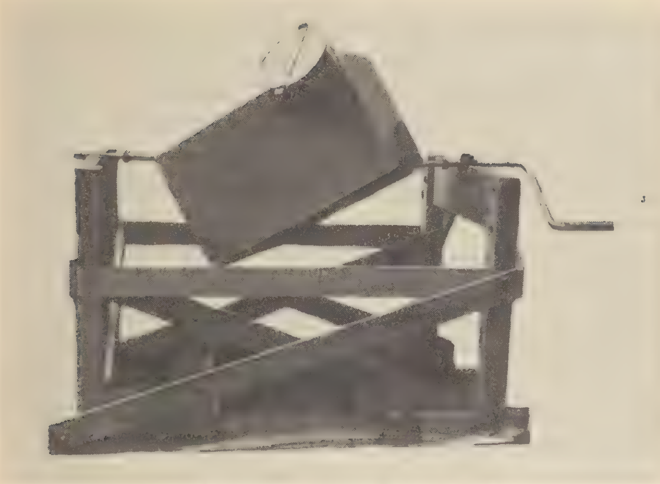
MATERIALS, EQUIPMENT, AND LARVICIDAL TECHNIQUE

*PARIS GREEN

As stated previously, paris green in malaria control is applied usually as a dust mixture. It is diluted with an inactive material such as hydrated lime, soapstone, talc, or road dust. The addition of a diluent is necessary to avoid overdosage and to distribute small amounts (usually 0.5 to 1 pound per acre) of paris green over a large area. Thus, in order to distribute one-half pound of the active larvicide over an acre of breeding surface, we must apply 5 pounds of 10 percent (by weight) paris green dust. The ratio of paris green to diluent (by weight) varies from 1:1 for some airplane dusting to 1:99 for broadcasting by hand. For rotary hand dusters and most power equipment, dilutions of 1:9 and 1:19 are commonly used.

Mixing is important. It must be done carefully and thoroughly. Hand operated mechanical mixers are most frequently used, but larger projects often employ power mixers. One common type of hand mixer consists of a metal drum or box mounted eccentrically on a horizontal shaft. After measuring, the paris green and diluent are placed together in the mixer which is revolved by a crank-like handle at one end. About five minutes cranking, clockwise and counter-clockwise, is sufficient to produce a well-mixed dust.

See rules governing handling of paris green in appendix.



Rectangular Hand Dust Mixer

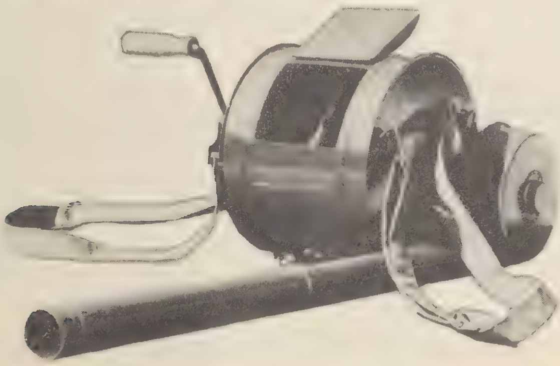
Converted Oil Drum Mixer

Most power mixers used are standard commercial models sold by agricultural insecticide manufacturers. The most commonly used make is composed of a steel hopper, clutch, and electric motor (5 H.P.) or gasoline engine (6 H.P.) mounted on a flat bed plate. The hopper is equipped with a high speed vertical rotor which whips the paris green and diluent into a fluff. Mixing with most diluents is completed in less than a minute. This equipment has a nominal hopper capacity of 100 pounds. It will easily mix 50 pounds of diluent and the proportionate amount of paris green and has a maximum capacity of 2½ tons of mixed dust per eight-hour day. The mixing operation can be expedited by quick opening inlets and outlets in the hopper and provision for the gravity discharge of mixed dust directly into bags or drums.

The rate of application used (dosage) depends principally upon density and type of vegetation to be penetrated, amount of scum and flotage on the water surface, and other practical problems of distribution. Field tests with routinely used equipment are recommended. This will help in determining the most economical, effective dosage and will improve the work generally, especially if the tests are also used to show the dusting laborers the relationship between uniform distribution (coverage) and larval kill. The initial application rate before trial should be from one-half to one pound of paris green per acre, or from five to ten pounds (10 per cent paris green by weight) of mixed dust per acre.

Hand rotary dusters (blowers or guns) are suitable for dusting most breeding places. But on large areas, power equipment or airplanes are most economical and often more effective. Hand dusters are best suited for small ponds, swamps and marshes, and for ditches, creeks and canals. They are also used in larger breeding places which are not accessible to trucks and boats and in areas where airplanes are not suitable or available. Hand dusters used for malaria control are standard commercial models used also for crop and orchard dusting. Where extensive dusting is to be performed, hand dusters with ballbearing cranks are essential to avoid overtiring the laborers.

The hopper of several makes holds about seven or eight pounds of dust. When loaded, the duster weighs approximately twenty pounds. The rate of discharge can be regulated between one and twenty pounds per acre by means of a valve at the hopper outlet.



Rotary Hand Duster

The effective range (radius of application) of hand dusters is affected by wind velocity, density of vegetation, application rate, etc. When wind direction and velocity are favorable (velocity between 2 and 5 miles per hour), this effective range varies from 100 to 150 feet. Careful manipulation of the dust gun with moderately high wind velocities may increase this to 200 feet or more. Vigorous cranking to increase the initial nozzle velocity is a factor but not so important as wind velocity. It must be noted that the heavier paris green settles from the dust cloud faster than the diluent. Thus the effective range does not extend to the limits of the visible cloud!

Note the Drifting Dust Cloud

Rotary Hand Duster in Operation

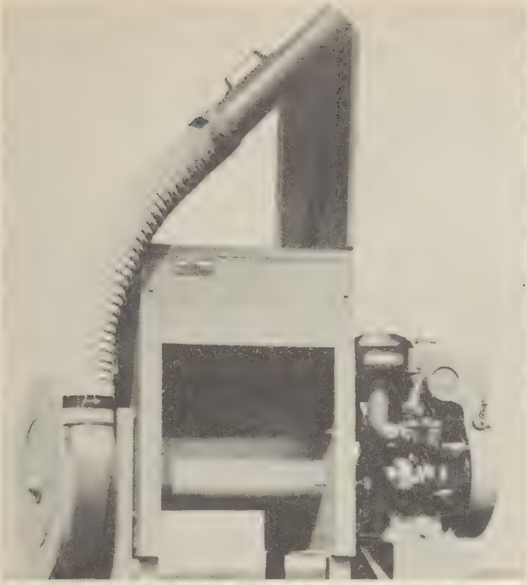
The outlet nozzle is generally held in a horizontal or slightly raised position by the laborer, who cranks continuously with the other hand while walking forward at a normal pace on the windward side of the breeding area. In this manner, a band of breeding surface located more than 20 feet and within 100 to 150 feet of his path is treated effectively except where heavy stands of brush or tall grasses intervene. Breeding surfaces from 5 to 20 feet distant may also be treated at the same time by alternately deflecting and raising the nozzle.

A different technique is used in dusting the edges or surfaces of canals, small creeks, or individual ditches. Here, if the laborer is walking along the bank, he is often directly above the surface to be treated and

must point the nozzle directly downward or attach a deflector supplied by the manufacturer. Since overdosage is inevitable even though cranking speed is reduced, it is better to use a 5 or 2½ per cent paris green mixture for laborers who are dusting this type of breeding place continuously.

Two types of power dusters are commonly used on trucks or boats. One is an independent unit consisting of a hopper, dust storage chest, and a motor to power a fan-blower. The other is similar, but the power is taken from the truck or inboard boat engine. The rate of discharge varies with motor speed and size of discharge opening (adjustable).

Power Duster Mounted on a Jeep



Independent Engine-Powered Duster

One make of independent engine-powered unit having wide use is offered in three sizes, with hopper capacities of 40, 50, and 100 pounds. The fan-blower is driven by 1-3/4, 2-1/3, and 6-1/2 horse power, air cooled gasoline engines respectively, with maximum speeds up to 3300 r.p.m.

One make of power take-off duster utilizes the same hopper as the power mixer described previously. A blower and flexible nozzle are fitted to the base of the hopper and both the mixing rotor and discharge blower are driven by a power take-off shaft connected to the boat or truck engine.

Power Duster Mounted in Boat

The effective radius of application for power dusters is determined by the same factors described for hand dusters, and by size of motor. The maximum range under favorable conditions varies from approximately 400 feet for the smallest power duster, to as much as 1,000 feet for the power take-off type. Volume of dust cloud rather than nozzle velocity is responsible for effective kill at the longer distances. Although initial nozzle velocities of as high as 250 feet per second are reported by manufacturers, this force is largely dissipated in the first 50 to 100 feet; and the dust cloud thereafter is carried by the air currents in which it is launched.

Under average conditions, the two smaller sizes (1-3/4 and 2-1/3 H.P.) of power dusters are best adapted for treating water surfaces from 50 to 250 feet away from the point of application. The two larger sizes (6-1/2 H.P. and power take-off) are indicated where distances of 250 to 500 feet are also involved. Distances greater than 500 to 600 feet should not be scheduled for routine power dusting, since consistent results cannot be expected.

Hand dusting is frequently used to supplement power dusting by truck for breeding surfaces within 50 feet of power dusting points, since power equipment "overreaches" this zone, due to high initial velocity of the dust cloud. In power dusting by boat, the need for supplementary hand dusting in the 0 - 50 foot zone generally can be avoided, since the boat usually travels on the water side of the breeding areas bordering the shoreline and can follow an offset lane 50 feet away. However, supplementary hand dusting is often necessary along the edge of the shore where the width of marginal breeding surface is too great to cover with the power duster on the water side, or bands of thick brush or tall grasses near the water's edge are wide and dense enough to shield the shoreline from the power dust cloud.

The power duster nozzle is held in a horizontal position during a large part of the dusting period. It should be elevated slightly to reach distant breeding surfaces when the air is still near the water surface but in motion 15 to 20 feet above the water. Con-

versely, it is depressed slightly to dust places near at hand. The nozzle is held at right angles to the path of travel of the truck or boat where the vehicle follows a course paralleling the edge of the breeding area. Occasionally, breeding places can be approached by truck from only a few points, even where access trails have been made. Here, points of vantage should be chosen, preferably 5 to 10 feet above water level, from which radial distribution can be accomplished by swinging the nozzle in an arc. Much skill and experience are required on the part of a power duster operator, but expenditure of considerable effort in selecting and training a good operator pays dividends, since a few minutes of power dusting often save hours of hand dusting or days of hand oiling.

Most airplane dusting has been with a biplane, equipped with a dust hopper in the front cockpit. An agitator, generally powered by a small wooden propeller mounted on the front of the lower wing, is installed in the hopper. One type of agitator is made of heavy piano wire in the form of a cylinder. The dust is discharged through an air funnel (Venturi type) under the hopper. When the plane flies at low altitudes (15 to 50 feet above the water), the dust is distributed in swaths 50 to 200 feet wide.

For most airplane dusting, lower dilutions are usually employed than for hand and power

Airplane Dusting Paris Green

dusting. The percentage of paris green may be as high as 25 per cent or more by weight. One study has shown that a low speed biplane may cover as much as 373 acres per hour.

Close-Up of Venturi

Paris green dusting of open areas by hand, power, or airplane generally should be performed in the early morning, when the air is relatively still; although suitable conditions are sometimes found in the late afternoon or on cloudy days when air conditions are favorable. During other daylight hours, the air becomes warm; and air currents will carry the dust up and away so that little paris green reaches the water surface on open ponds and marshes.

Air turbulence which is too light to carry off the dust may still cause spotty coverage. Therefore, work must be planned so that dusting of these places can be done during suitable hours, and other duties should be reserved for the remainder of the day. Some breeding places which are protected from breezes and thermal air currents may, however, be dusted at almost any time. These include ditches and creeks where the bank serves as a windbreak, or larger breeding surfaces shielded from breezes by heavy stands of trees, brush or tall grasses.

Paris green has also been applied by broadcasting by hand (1 part paris green to 99 parts of road dust), in an emulsion with kerosene and water, and in suspension with water. But these methods are seldom, if ever, used or recommended for use in this country.

PETROLEUM OILS

As a larvicide, diesel or fuel oil is generally applied without dilution, but may be used in an emulsion. In general mosquito control, phenol or cresol is sometimes added to oil to increase its toxicity. Oil is also distributed under high pressure "mixed" with water. It is used as a dual purpose larvicide in malaria control where both malaria and nuisance mosquitoes are present. Because spreading of the oil film is impeded by thick grasses, pond weeds, and many kinds of dense flotage, the cost of oil larviciding may be increased greatly by necessary extensive clearing work. Best results are obtained in breeding places that are relatively clean and exposed.

Power spraying is more economical than hand spraying on many large areas (reservoirs, lakes, and ponds) or on numerous small roadside breeding places accessible by boat or truck. Hand-operated equipment is suitable on smaller places, for scattered isolated pools and ponds, or on large areas not accessible to power sprayers. Power and hand-equipment are often used together. For example, on large lakes, there may be adjacent small pools or bights impossible to reach by truck or boat which may be treated with hand operated equipment. The distance (radius of application) the larvicide can be thrown from hand sprayers is limited to from 10 to 15 feet. This is greatly increased (to 100 feet or more) by use of power equipment developing high pressures.

Rate of application (dosage) will vary widely with type and density of vegetation and flotage, length of shoreline in relation to breeding surface, and kind of equipment used. Applied straight, 10 to 40 gallons of oil per acre may be needed. Used in emulsion form, as little as 6 gallons of oil (not spray) per acre may suffice.

Four types of hand sprayers are in use on oil larviciding. One is the hand air-pressure sprayer, capacity from 2 to 5 gallons, consisting of a cylindrical steel tank equipped with an air plunger pump, rubber discharge hose, and spray nozzle. In spraying, the operator first fills the tank about three-quarters full, then pumps in air with the hand pump to a pressure of about 35 pounds. The sprayer is carried by a shoulder strap. Its principal advantages are (1) portability, (2) free use of the operator's hands in directing spray and in getting through thick brush. The chief disadvantage is that it must be taken off and "pumped up" frequently to maintain adequate pressure.

Another type, not so commonly used in malaria control, is the "trombone" sprayer. It has a knapsack type tank (about 5 gallons capacity), the usual hose fittings, and a double-action hand pump fitted immediately behind the nozzle. Both hands are employed in spraying and pumping; this does not permit good aim.

Two other types of knapsack sprayers have been commonly used in mosquito control. Both have brass piston pumps mounted inside the tank with an air chamber and a jet agitator (this is desirable for emulsions). One type has the pump lever located under the tank; in the other, the lever is fitted at the top of the tank. The latter has a swivel pump handle which hangs in front of the worker at elbow level. Both are convenient to carry on the back. Pumping is done with one hand while the spray is directed with the other. The top lever type is generally preferred, since the pumping position is more comfortable, although the swinging handle sometimes snags in heavy brush. These sprayers hold 4 to 5 gallons of larvicide.

The time required to fill hand sprayers is an important element of larvicidal cost. In part, this can be held to a minimum by proper labor management - to avoid "bunching" of laborers waiting to refill spray cans - but various mechanical improvements have been developed in the field. Generally, the spray cans are filled from 55 gallon steel oil drums standing upright in trucks. Several drums may be placed along the center line of the platform of a 1½ ton stake body truck, leaving space for seating labor and carrying spray cans on each side. The battery of drums is connected to a 2-inch pipe line running underneath a false floor, with projecting outlet pipes at the rear for filling cans. Another device involves connecting a 4 or 5 gallon

Air Pressure Sprayer

Trombone Sprayer

hand air-pressure empty spray can to an oil drum to accomplish delivery of the oil under

Top Lever Knapsack Sprayer

Bottom Lever Knapsack Sprayer

pressure directly from the drum.

The Bordeaux nozzle is most commonly used on knapsack-type sprayers. This nozzle is adjustable from a small jet stream to a fan-shaped mist spray. It seldom clogs and can be cleaned easily. The disk nozzle is more generally used with air pressure sprayers. Most disk nozzles are equipped with screw plungers for quick adjustment of the spray. Power sprayers employ nozzles (guns) specially designed and constructed to withstand high pressures.

Power sprayers, operated under pressure as high as 300 pounds, are used to larvicide extensive breeding places that are accessible to truck or boat. These consist usually of a gasoline engine, a pump, and tank with multiple hose connections, mounted on a chassis. Tank capacity is from 50 to 500 gallons. They are supplied generally with one or two hoses, each at least 100 feet long.

Power Spray Unit Mounted on Jeep

Small
Power Unit
in
Operation

Large
Power Unit
on
Heavy Truck

Large Power Unit in Operation

Water-Oil Sprayer Mounted in Shallow Draft Boat

A special type of power unit used on some large reservoirs is the water-oil sprayer mounted in shallow draft boats. One model, used extensively by the Tennessee Valley Authority, has a centrifugal pump operated by a gasoline engine. A small fuel line connects the oil tank to the suction side of the pump, and a larger pipe through or over the side of the boat carries water to the pump intake. The boat is propelled by an outboard motor. In this way, a small amount of oil is mixed with a large volume of water and discharged under high pressure. This method is very effective for breaking up flotage, penetrating dense vegetation, and reaching inaccessible spots.

A number of miscellaneous methods, such as drip cans, submerged oil-soaked sandbags or saw dust, etc., have been used but these rarely are suitable.

EMULSIONS

The stock solution of the pyrethrum-oil emulsion as developed at the New Jersey Agricultural Experiment Station contains the following:

A. Six gallons of kerosene or similar light oil plus 40 ounces of (2% pyrethrins) pyrethrum extract.

B. Three gallons of water.

C. Six ounces of emulsifier (sodium lauryl sulfate) or 24 ounces of 40% liquid potash soap.

To prepare the emulsion, an emulsifier is added to the water and the mixture agitated thoroughly. Then the kerosene or light oil containing the pyrethrum extract is added slowly while agitation is continued. Stability of the emulsion depends on effective agitation. A power sprayer or hand sprayer can be used to form the emulsion when small batches are to be mixed.

The stock emulsion is then diluted 1:10 (generally) with clean water from the jobsite to make the spray. To prevent clogging of spray nozzles, *always strain the dilution water.* The pyrethrum-oil larvicide can be applied with the same equipment described for oil larvicides. The quantity of spray needed per acre will vary from 25 to 50 gallons (2½ to 5 gal-

lons of stock emulsion) depending on the nature of the breeding area and the kind of sprayer used. By comparison with straight oil, substantial saving is realized in weight of material hauled, because only the concentrate need be carried to the breeding place.

The oil-water emulsion referred to under "Emulsions" is made by machine or hand mixing diesel oil or kerosene with an emulsifier (a sperm oil, Nopco 1216, a resin, B1956, or an amine, 230X) and water. The U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine, has developed an emulsion using diesel or fuel oil with 3 or 4 per cent emulsifier. One part of this mixture is added to seven or more parts of water to make up the spray. For fresh water breeding places, the following formula is recommended:

OIL — WATER EMULSION FORMULA

3	gallons diesel or fuel oil
1	pint emulsifier
15 - 18	gallons water

First, the oil and emulsifier are mixed thoroughly. Water is then added with strong stirring. The resulting spray is effective when applied at a rate of about 40 gallons (6 to 7 gallons of oil) per acre. This larvicide has not had wide enough use to permit conclusions as to its applicability as an anopheline larvicide.

COST AND PERFORMANCE RATES

Larviciding costs are widely variable, both between individual breeding places and different area-wide projects. Important factors are size and character of breeding places, accessibility to larvicidal crews (hand and power), type and condition of equipment, efficiency of labor and supervisory personnel, quality of work performed, etc. The significance of these elements is more or less obvious. By quality of work performed is meant not only thoroughness, as reflected in effectiveness of kill and absence of places missed, but selectivity of operations. On projects otherwise similar, indiscriminate larviciding may show lower costs per acre than one on which selective treatment of known malaria mosquito breeding is practiced due to savings in overhead. But this results in excessive total cost of project operation.

The comparative cost of different larvicides varies greatly. While paris green dusting is never more expensive than oil larviciding, the direct cost of oiling may vary from about 25 per cent greater for small ditches to as much as ten times greater for some ponds. In most "acreage" breeding surfaces, the greater effective radius of application for paris green is an outstanding advantage. Precise comparison of costs between these two larvicides is difficult because of indirect costs which are against oil. These include weight of materials to be hauled, amount of clearing required, and time spent in filling the spraying equipment.

TYPE OF ACTIVITY	MAN - HOUR* ACCOMPLISHMENT	LARVICIDE PER UNIT SURFACE TREATED
OIL LARVICIDING (No. 2 Diesel Oil)		
Hand Application		
Small Ditches	0.75 MH/1,000 ft.	7 gal./1,000 ft.
Ponds and large ditches	3 - 6 MH/acre	15 - 30 gal./1,000 ft.
Power Application		
Small ditches, from trucks	0.10 MH/1,000 ft.	5 - 10 gal./1,000 ft.
Ponds and large ditches, from boats	0.50 MH/acre	20 - 30 gal./acre

PARIS GREEN LARVICIDING (10% by Weight Paris Green)

Hand Application		
Small ditches	0.40 MH/1,000 ft.	3 - 6 lbs./1,000 ft.
Ponds and large ditches	1 - 2 MH/acre	10 - 20 lbs./acre
Power Application		
Small ditches, from trucks	0.10 MH/1,000 ft.	3 - 6 lbs./1,000 ft.
Ponds and large ditches, from trucks	0.3 - 0.5 MH/acre	10 - 20 lbs./acre
Ponds and large ditches from boats	0.3 MH/acre	10 - 20 lbs./acre
Airplane Application		
Large ponds and other breeding areas	Properly equipped biplane can dust from 21 - 30 acres per minute, using mixture 25% paris green by weight.	

**Does not include supervision above foreman.*

PERFORMANCE RATES FOR SOME TYPES OF LARVICIDAL EQUIPMENT

TYPE OF EQUIPMENT	RATE OF DISCHARGE
DUSTERS	
Root Model 2 - hand	0.6 lb./minute
Root Model Y - power	8.0 lbs./minute
SPRAYERS	
Meyers - knapsack, Bordeaux nozzle	0.5 gal./minute (fine spray)
Dobbins - " , disk nozzle	0.13 gal./minute

Hardie Power Sprayer	
Hardie gun with No. 5 nozzle plate, 150 psi pressure	1.0 gal./minute
Hardie Power Sprayer	
150 psi pressure - Hardie spray gun rebored with 1/8" plate hole	3.04 gal./minute
John Bean Sprayer	
500 psi pressure - Hardie gun rebored with 1/8" nozzle plate hole	6.13 gal./minute

Some figures on costs of larviciding under various conditions and using different kinds of equipment are shown in the preceding tables. These are given in man-hours per unit of breeding surface treated to avoid distortion due to abnormally high or low wage rates. Also given are theoretical performance rates of some larvicidal equipment when operated continuously at maximum output and at recommended application rates. Actual performance rates are, of course, only a small fraction of the theoretical rates, but these latter are helpful in making comparisons between different types of equipment and application methods.

The amount of oiling or dusting one worker can do per day obviously depends on such things as density and type of vegetation encountered, accessibility of breeding place, distribution factors concerned with spreading qualities of oil, and use of air currents to carry the dust. Experience has shown that on area-wide operations and under good conditions with little "carry", one man using hand equipment can oil from two to three acres per man-day. This includes all overhead time of the individual. This amount of area can be doubled under extreme optimum conditions but reduced in the same proportion under unfavorable conditions. At least three times as much area can be treated (under similar conditions) using paris green dust because of the greater radius of application possible with dusting equipment.

The use of power larvicidal equipment greatly reduces labor costs and is more effective in terms of mosquito reduction, particularly on large breeding areas accessible to truck or boat-mounted units. Often as much as 70 per cent in over-all costs may be saved by substituting power for hand equipment.

Regardless of costs, there are often extensive breeding places of the malaria vector that cannot be controlled except by airplane application of paris green. On the other hand, there are places where airplane larviciding is the most economical as well as the most effective method. The low-speed biplane commonly used can treat from 20 to 30 acres of breeding area per minute. The cost per acre-treatment for contract airplane dusting on the MCWA program has varied from $0.65 to $1.15. This does not include ground services for loading planes, entomological checking, etc.

Filling Spray Cans Efficiently

SELECTION OF APPLICATION METHOD AND TYPE OF LARVICIDE

An understanding and awareness of the following factors is necessary in making an intelligent approach to selection of application method and type of larvicide for anopheline species sanitation.

Effectiveness of larvicides and method of application selected are influenced directly by the character and extent of vegetation in breeding places. Type of vegetation is an ever present factor. Malaria mosquitoes, generally, require some form of it for protection and food. Occasionally, breeding may occur in temporary pools, small pockets of water which are free of mosquito predators and microscopic vegetation. (Example, temporary depression pools in flat areas which produce mosquitoes during the rainy season.) Here, microscopic forms of plant and animal life are present and they furnish food to the larvae. But usually some visible plant life is present, offering food and protection to the aquatic form of the mosquito. Such vegetation may be submerged but may "clip" the water surface at many points. It may be horizontal — lying flat or floating on the water, or emergent — extending above the surface and standing upright. Any of these three types of vegetation is a major factor influencing the effectiveness of the larvicide and the larvicidal method.

Oil is sprayed horizontally and is deposited in small droplets on the water. To be effective, these small drops must spread to form a continuous film on the breeding surface. Growths of submerged or floating vegetation, which break the water surface, impede the spread of oil. Within limits, this reduced spread may be overcome by increasing the spreading properties of the oil (using an oil emulsion, adding a spreader such as castor oil to diesel oil).

Collections of flotage composed of dead or decaying particles in the form of rafts prevent effective spreading of oil (this is called non-vital flotage). The high pressure spray of the water-oil spraying unit can be used successfully to break up such flotage mats and to increase the spread of the oil. This power unit also permits a considerable increase in the radius of application for oil larviciding.

Oil is less affected by emergent vegetation although such growths may often aggravate the flotage problem by serving as an anchorage for mats of limbs and debris of all sorts. The stems of emergent plants obstruct and deflect the oil spread to some extent, where growth is heavy. More important, dense emergent vegetation obstructs the path of the spray and may make breeding places inaccessible or greatly increase the cost of treatment.

Paris green dust may be applied horizontally through the air (by hand or power duster) or vertically (airplane), but in either case it drops vertically into position. Therefore, its effectiveness is not affected by spreading in the same sense as oil. It is not influenced directly, to any extent, by growths of horizontal (floating) or submerged vegetation. While the dust cloud penetrates thick stands of tall grasses and other aquatic plants remarkably well, paris green is air-borne. Hence, by impeding or deflecting air currents, emergent vegetation reduces the application radius of hand or power duster.

This interference is manifested in two ways — by deflecting the dust cloud (example, thick, tall brush or tree barrier in large pond) or by retarding or stopping air flow (example, a dense clump of tall cattails several hundred feet in diameter). Since the larvicide is dropped vertically, thick emergent vegetation has less effect on airplane dusting. But even so, tall thick stands of plants may increase larval survival and the required application rate.

Under extreme conditions, where emergent vegetation is so dense as to completely still air currents, the effective application radius of hand and power dusters is limited to distance of travel resulting from the initial nozzle velocity. In the worst situations experienced by the authors, this was about 25 feet for hand dusters and 50 feet for small power dusters. In each case, this distance

is materially greater than for hand and power oil sprayers. Fortunately, conditions of this type are rare since such thick emergent growth usually creates dense shade which inhibits production of the malaria vector found in this country.

There follows below a comparative summary of the advantages of paris green and diesel oil, since these are the two most commonly used anopheline larvicides.

SUMMARY OF PARIS GREEN ADVANTAGES

1. *Most economical larvicide. Lowest overall cost. Saves materials, equipment, manpower and transportation.* On a state-wide program with 5,000 acres of breeding surface, one dusting (using hand methods) requires materials costing approximately $1,360 and weighing 25 tons. One oiling requires materials costing approximately $8,000 and weighing nearly 400 tons. A laborer can dust about three times as much acreage as he can oil. Oiling requires more larvicidal equipment, more trucks to haul labor, materials, and equipment, and more labor to deliver the larvicide to the jobsite. Paris green dusting requires less clearing to condition breeding places for effective treatment, fewer paths and trails, and lighter vehicular equipment which can reach places not accessible to heavier trucks.

2. *Most effective larvicide where horizontal or submerged vegetation is dense.*

3. *Can reach breeding places not accessible to oil* due to greater radius of application from ground and suitability for airplane application.

4. *Less fatiguing to labor.* A hand dust gun, loaded, weighs about 20 pounds. One load will treat one-half to one acre without returning for refill. A knapsack sprayer, loaded, weighs about 45 pounds, and one load will treat only about one-fourth of an acre. Men walking in deep water with rubber boots can carry a 20 pound load to places inaccessible with a 45 pound load.

5. *Avoids oil burns* from leaky knapsack sprayers; *does not stain and destroy clothing*, is *not destructive to rubber boots*, as is oil.

SUMMARY OF ADVANTAGES OF DIESEL OIL LARVICIDE

1. *More effective than paris green in clean or relatively clean breeding places.* (A good paris green kill is 90 per cent of 2nd, 3rd, and 4th stage larvae. Oil will kill 100 percent where conditions are favorable.)

2. *Can be applied less frequently than paris green* because it kills all stages of larvae, pupae, and some eggs. In places where dusting is needed every seven days, oil could be applied every nine or ten days.

3. Under some conditions, *prevents egg laying* by female mosquitoes.

4. *Avoids burns in folds of skin peculiar to paris green and lime* (when lime is used).

5. *Labor can be trained more easily and inspection of spraying work is easier.* (It is easier for laborers to see where oil is being placed and to apply the correct dosage rate. Inspectors can check more easily for uniform coverage and places sprayed.)

6. *Less affected by weather.* Application of paris green to open breeding areas is dependent on favorable air velocities. (For this reason, oiling laborers can larvicide throughout the working day, while dusting often can be performed only in the early morning unless the project zone contains protected breeding places.) Heavy rains occurring immediately after larviciding affect paris green more than oil.

PLANNING AND ORGANIZATION OF LARVICIDAL WORK

On most MCWA projects, breeding places are numerous, sometimes widely separated, often extensive. Careful planning to coordinate and conserve resources in personnel, materials, and equipment is a prerequisite for economical and effective control. Organization of larvicidal crews, division of areas into zones and districts, selection of application method and larvicide must be based on entomological and engineering evaluation of individual projects.

In general, larvicidal operations follow routine schedules, but planning and organization must include the following considerations:

1. Location, character, and extent of breeding places of the malaria mosquito with respect to other malaria attributes. (Also applicable to selection of method and larvicide.)

2. Seasonal incidence of the vector species and seasonal variations in the breeding cycle.

3. The desirability of maintaining key larviciding personnel by providing employment during the off-season on minor drainage, maintenance, clearing. and trail-building activities.

4. The necessity for flexible management to meet emergencies due to unfavorable weather, equipment breakdown, and seasonal variations (Item 2 above) in mosquito densities.

On MCWA projects, it is the practice to divide an area into zones which may be subdivided into districts. Depending on size, each zone or district is covered by a larvicidal crew. The crew should generally be small, three to eight men. Large crews are difficult to supervise and may cause wastage of larvicide and man-hours due to excessive overlapping of crew sections. A good plan is

to have a three or four man crew with one of the men designated as a working foreman or sub-foreman. Large crews may need a foreman plus an assistant foreman.

Normally, crews follow weekly routine procedures scheduled on a basis of larval collections. But it must be remembered that this kind of plan ignores the proper tactical utilization of adult "A" station counts. Therefore, some flexibility in crew direction is necessary so that routine work may be dropped in order to concentrate the attack in locations where "A" station mosquito counts remain high. In other words, control procedures must be coordinated at all times with inspection findings.

Frequently, considerable advantage may result in provision for changing from hand to power equipment and vice versa. During dry months, extensive breeding places suitable to power larviciding sometimes develop into small, scattered places more amenable to hand operations. This facility for switching types of equipment to meet the current problem will save labor, materials, and equipment in many cases.

Larvicidal crews should be carefully selected. Physical fitness, dependability, and intelligence are important points to consider in hiring personnel. The effectiveness of any larvicidal program depends more directly on the efficiency of the crew than on any other single factor.

During operations, crews will often find important maintenance work that can be done immediately, thereby improving the efficiency of larviciding and preventing or reducing future problems. This may involve such work as removing obstructions from ditches and culverts, clearing access trails, and miscellaneous equipment maintenance. As the key man, it is the crew foreman's responsibility to keep his supervisor currently informed in regard to equipment and material needs, special problems encountered in the field, and to offer suggestions to improve the efficiency of the work. In turn, it is the Area Supervisor's duty and responsibility to train his foremen adequately and to see that they exercise these responsibilities.

A noted authority has referred to inspection as "the essential bookkeeping of the business." It is that — and more. The inspector has pre- and post-operational responsibilities aside from observations directly related to larvicidal activities. Unfortunately, the mosquito's environment frequently changes from season to season — even from week to week. So, the inspector must locate and evaluate new breeding places as well as check on the effectiveness of current larviciding. For more detail on this phase of larviciding, refer to the MCWA "Entomological Field Handbook."

APPENDIX

RULES GOVERNING HANDLING OF PARIS GREEN

Paris green is poisonous to man, animals, insects, and other life; but if handled with reasonable caution, it is not dangerous. Indeed, many materials in daily use (plants, kerosene, white lead, etc.) are poisonous to man but are used with no ill-effects. Paris green has been used for years to control insect pests in cranberry bogs and potato fields. Another arsenic compound, also poisonous to man and animals, has been used for many years in the fight against the boll weevil.

In routine handling of and dusting with paris green for mosquito control, it is practically impossible for a worker to receive a fatal dose of the chemical. Some individuals

Wearing Dust Masks at Mixing Station

who handle paris green daily (this is also true of hydrated lime, one diluent used) may develop a skin rash which usually disappears quickly when promptly treated.

The following rules will prevent paris green poisoning:

1. In mixing or applying paris green dust, *avoid undue exposure. Do not allow the dust to accumulate on skin surfaces, in the eyes or nose, or in folds of the skin where chafing may occur.*

2. *Use dust mask to avoid inhaling the dust*, especially when mixing indoors.

3. In dusting, *the operator should stand with his back to windward*, thus protecting himself from the dust and using the air currents to distribute the larvicide.

4. Handlers of paris green should *bathe at the end of each day's work. Work clothes should be changed or washed frequently.*

5. *Individuals showing signs of sensitivity to paris green should not be employed on dusting or mixing.*

6. *Cases of skin rash should receive immediate treatment and should avoid exposure to paris green until cured.*

SPECIFICATIONS FOR PARIS GREEN USED IN MOSQUITO CONTROL

HAND AND POWER DUSTING

The paris green shall contain a minimum of 50 per cent arsenious oxide — no more than 2½ per cent being water-soluble. At least 95 per cent shall pass a 325-mesh sieve, using water as the wetting medium, the material being gently brushed on the screen surface with a camel's hair brush.

A two hour exposure of 2nd, 3rd, and 4th stage anopheline larvae to a 1:9 mixture of paris green and diluent (hydrated lime or soapstone) applied at the rate of 1 to 1.5 pounds ofparis green per acre shall give a complete kill within 24 hours.

AIRPLANE DUSTING

The paris green must be of such fineness that at least 95 per cent shall pass a 200-mesh screen and at least 85 per cent shall pass a 325-mesh screen. At least 75 per cent shall consist of particles 20 microns or more in diameter, the material to be gently brushed on the screen surface with a soft camel's hair brush using water as a medium. It must contain approximately 50 per cent arsenious oxide with no more than 3½ per cent being soluble in water (all percentages by weight).

A period of three weeks is necessary before final acceptance of shipment. This period is needed to test samples of the product to be delivered by the successful bidder.

SPECIFICATIONS FOR OIL USED IN MOSQUITO CONTROL

Type of oil: light distillate fuel or diesel oil.

Gravity (A.P.I.): 27 - 33

Flash point: 130°F. or higher

Viscosity S.U. (a) 100°F.: 35 - 40

Spreading coefficient: 16 dynes/cm. or higher

Distillation:	10% - 430° - 450°F.
	50% - 510° - 550°F.
	90% - 630° - or higher

CONVERSION TABLE FOR SURFACE AREAS

144	sq. inches	= 1 sq. foot
9	sq. feet	= 1 sq. yard
30¼	sq. yards or 272½ sq. feet	= 1 sq. rod
160	sq. rods	= 1 acre
1	acre	= 4,840 square yards
		= an area about 69 x 70 yards
		= a circular area 80 yards in diameter
		= a 4 yard canal, 1200 yards in length
		= a yard ditch, 4800 yards long (about three miles)
640	acres	= 1 square mile